Impacts of Climate Change on Global Energy Production and Consumption:
Recent Literature and a Useful California Case Study

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Presentation Outline

I. Context

II. Selected Review of International Impact Analyses

III. U.S. Case Study: California

IV. Lessons Learned

Presentation Context

- Traditional focus has been on GHG mitigation policy effects to this sector.

- General lack of impacts information for the energy sector, but base of international literature is growing.

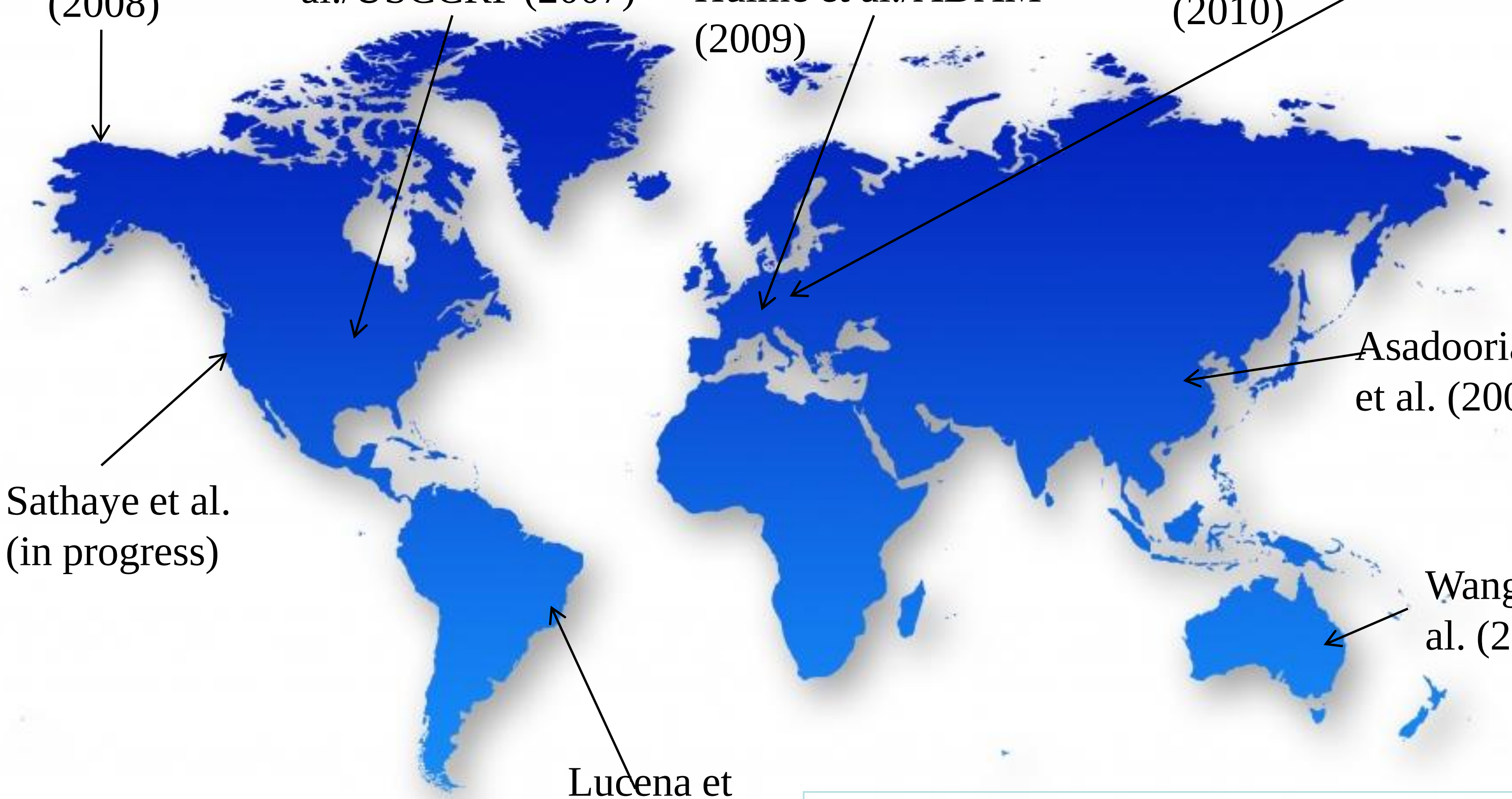
- Qualitative "scoping studies", global, and regional risk assessments are underway.

- Analysis methods carried out in our ongoing research into California energy infrastructure at risk to climate change could be replicated in other regions, especially probabilistic and risk-based mapping.

Presentation Context: Parameter Impacts on Energy Demand and Supply

Hydro-meteorological and/or climate parameter	Select energy uses
Air temperature	Turbine production efficiency, air source generation potential and output, demand (cooling/heating), demand simulation/modeling, solar PV panel efficiency
Rainfall	Hydro-generation potential and efficiency, biomass production, demand, demand simulation/modeling
Wind speed and/or direction	Wind generation potential and efficiency, demand, demand simulation/modeling
Cloudiness	Solar generation potential, demand, demand simulation/modeling
Snowfall and ice accretion	Power line maintenance, demand, demand simulation/modeling
Humidity	Demand, demand simulation/modeling
Short-wave radiation	Solar generation potential and output, output modeling, demand, demand simulation/modeling
River flow	Hydro-generation and potential, hydro-generation modeling (including dam control), power station cooling water demands
Coastal wave height and frequency, and statistics	Wave generation potential and output, generation modeling, off-shore infrastructure protection and design
Sub-surface soil temperatures	Ground source generation potential and output
Flood statistics	Raw material production and delivery, infrastructure protection and design, cooling water demands
Drought statistics	Hydro-generation output, demand
Storm statistics (includes strong winds, heavy rain, hail, lightning)	Infrastructure protection and design, demand surges
Sea level	Offshore operations, coastal energy infrastructure

Selected Research List: Global, National and Local



GLOBAL:

- Vergara et al./World Bank (in progress)
- Petrick et al. (2010)
- Wilbanks et al./IPCC-AR4 (2007)

Selected Research: Global and Multi-national

Climate impact on energy demand:

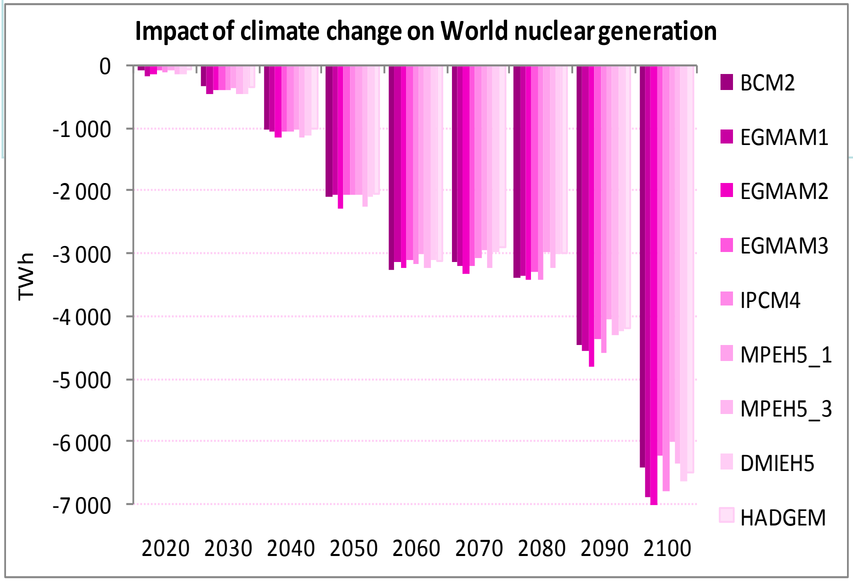
- **Heating Demand:**
  - Models typically show a decline in heating demand with rising temperatures
  - **e.g.,** Mina et al.(2010) using the A1B reference scenario in the POLES model show a decline that ranges from 200-300 Mtoe (-38% to -62%) by 2100.
- **Cooling Demand:**
  - Models show an increase in cooling demand with rising temperatures
  - **e.g.,** Increase in cooling demand is typically lower than the increase in heating demand – 60-130 Mtoe in the POLES model

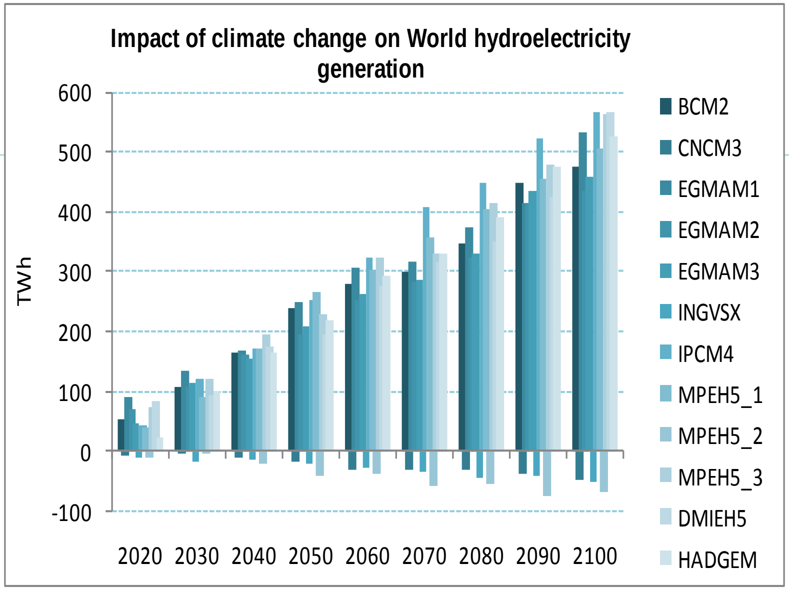
Selected Research: Global and Multi-national

Climate impact on energy supply:

• Quantitative analysis of global supply options is limited to date

• **e.g.,** POLES model shows that hydroelectricity generation may increase or decrease depending on the scenario, while nuclear and thermal generation declines by 2100





Selected Research: National

~Least-cost adaptation options for the Brazilian electric power system (Lucena et al. 2010)~

- Researchers applied an integrated resource planning approach to calculate least-cost adaptation measures to a set of projected climate impacts in 2100 on the Brazilian power sector.
    - Used MAED (demand) and MESSAGE (supply) models, and A2 and B2 scenarios
- Focus is on impacts on electricity demand, hydropower capacity factor, and natural gas efficiency
    - Electricity demand increases in residential and service sectors by 6% and 5%
    - Hydropower firm capacity factor declines by about 30%
    - Natural gas generation decreases by about 2%
- Above impacts are offset by efficient adaptation technologies, and increased use of renewable, nuclear and thermal plant use

Selected Research: Local/Regional

~Alaska Infrastructure at Risk (Larsen et al. 2008)~

• Developed preliminary model to estimate quantitative risk to AK public infrastructure, including energy systems. Model estimated additional costs with and without adaptation scenarios and included probabilistic framework. Researchers acknowledged shortcomings including the need to: 1) improve count/value of infrastructure, 2) develop "ground-truthed" damage functions, and 3) properly discount uncertain future risk to the present.

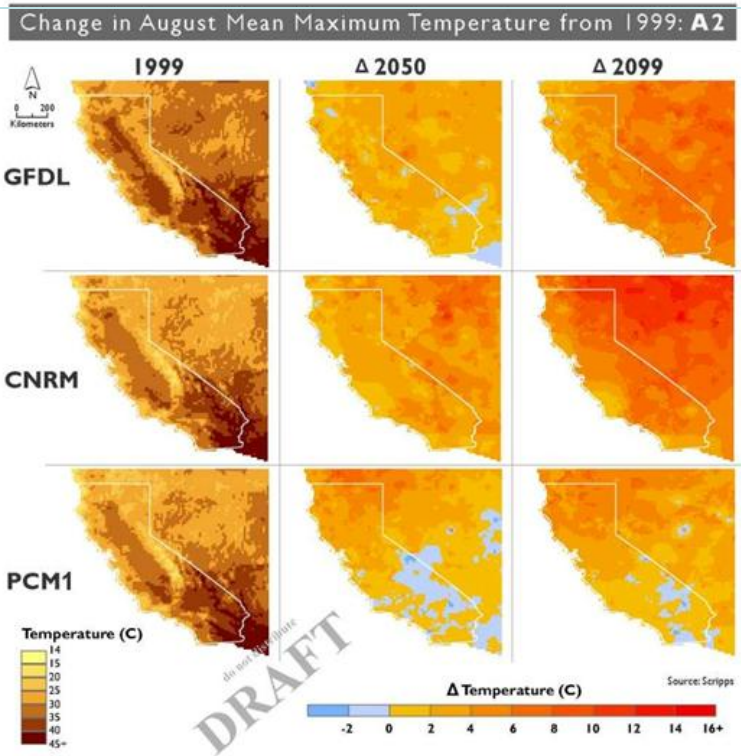
~California Energy Infrastructure at Risk (Sathaye et al.; in progress)~

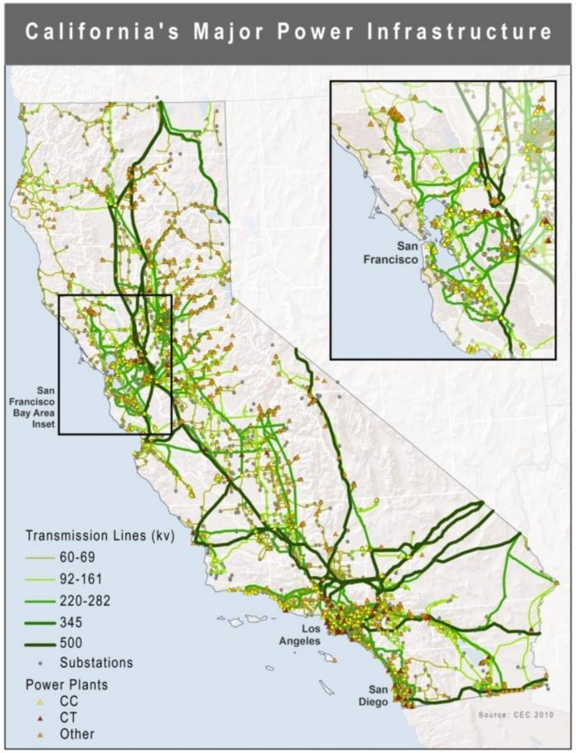
• Estimating risk to power plant, substation, and transmission line performance to projected temperature maximums. Team is overlaying reported energy infrastructure locations on top of sea-level rise and wildfire projections and visiting sites to ground-truth modeled results.

Case Study: Risk to CA Energy Infrastructure

BACKGROUND:

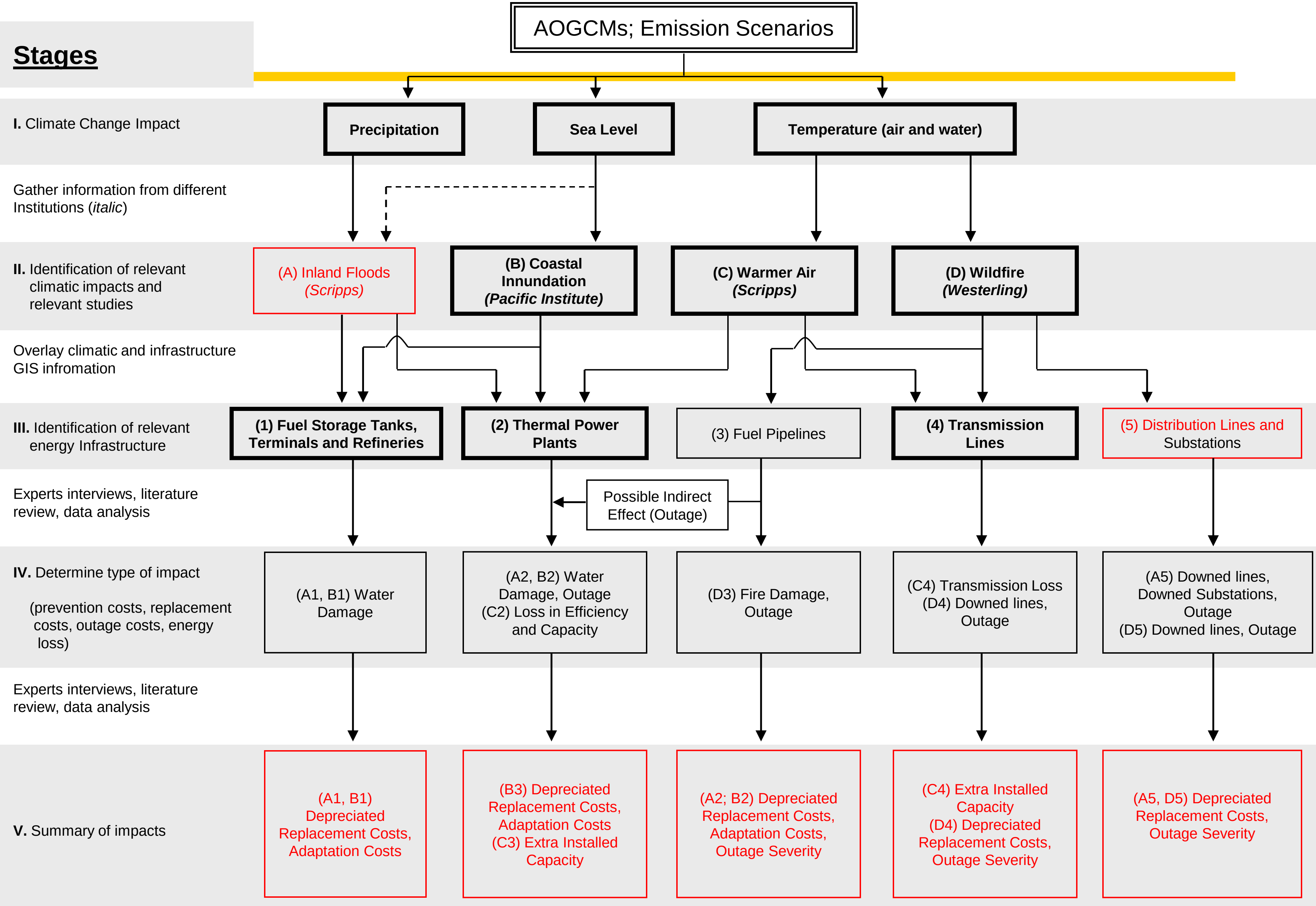
- California Energy Commission funded study to estimate power demand and explore physical risk to CA energy supply system.
- Technical advisory committee, including power sector stakeholders, provide feedback on data sources and methods.
- Estimated risk for A2 and B1 scenarios for three time periods up to 2100





BASIC METHOD:

- Coupled downscaled AOGCM projections to electrical system thermal equations to estimate changes to system capacity and demand from increased ambient temperature.
- Overlaid sea-level rise estimates and wildfire projections with known location of CA energy infrastructure.



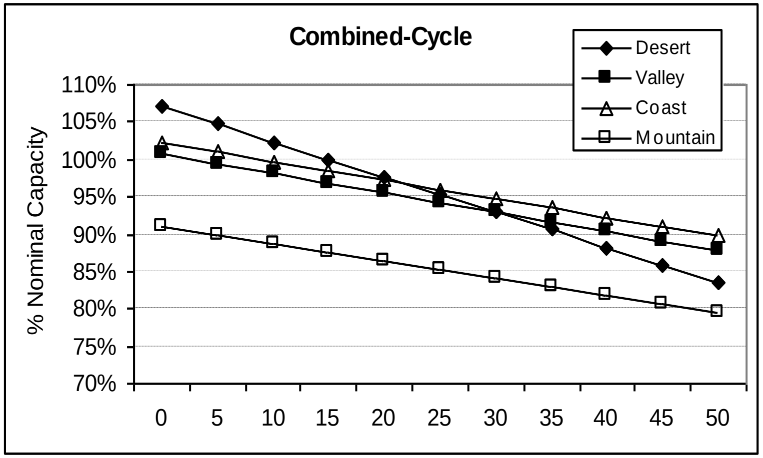
Stages
AOGCMs; Emission Scenarios
I. Climate Change Impact
Precipitation
Sea Level
Temperature (air and water)
Gather information from different Institutions (italic)
II. Identification of relevant climatic impacts and relevant studies
(A) Inland Floods (Scripps)
(B) Coastal Innundation (Pacific Institute)
(C) Warmer Air (Scripps)
(D) Wildfire (Westerling)
Overlay climatic and infrastructure GIS infromation
III. Identification of relevant energy Infrastructure
(1) Fuel Storage Tanks, Terminals and Refineries
(2) Thermal Power Plants
(3) Fuel Pipelines
(4) Transmission Lines
(5) Distribution Lines and Substations
Experts interviews, literature review, data analysis
Possible Indirect Effect (Outage)
IV. Determine type of impact
(prevention costs, replacement costs, outage costs, energy loss)
(A1, B1) Water Damage
(A2, B2) Water Damage, Outage
(C2) Loss in Efficiency and Capacity
(D3) Fire Damage, Outage
(C4) Transmission Loss
(D4) Downed lines, Outage
(A5) Downed lines, Downed Substations, Outage
(D5) Downed lines, Outage
Experts interviews, literature review, data analysis
V. Summary of impacts
(A1, B1) Depreciated Replacement Costs, Adaptation Costs
(B3) Depreciated Replacement Costs, Adaptation Costs
(C3) Extra Installed Capacity
(A2; B2) Depreciated Replacement Costs, Adaptation Costs, Outage Severity
(C4) Extra Installed Capacity
(D4) Depreciated Replacement Costs, Outage Severity
(A5, D5) Depreciated Replacement Costs, Outage Severity

Overview of Research: Assessing vulnerability of….

1. *Electricity infrastructure* to **warming temperatures**.

Without additional cooling equipment, CA <u>natural gas-fired power plants</u> typically lose ~0.7% to 1.0% of capacity for every degree of ambient temperature above 15C.

- Literature review to determine quantitative relationships between ambient temperature and power plant, substation, and transmission capacity.



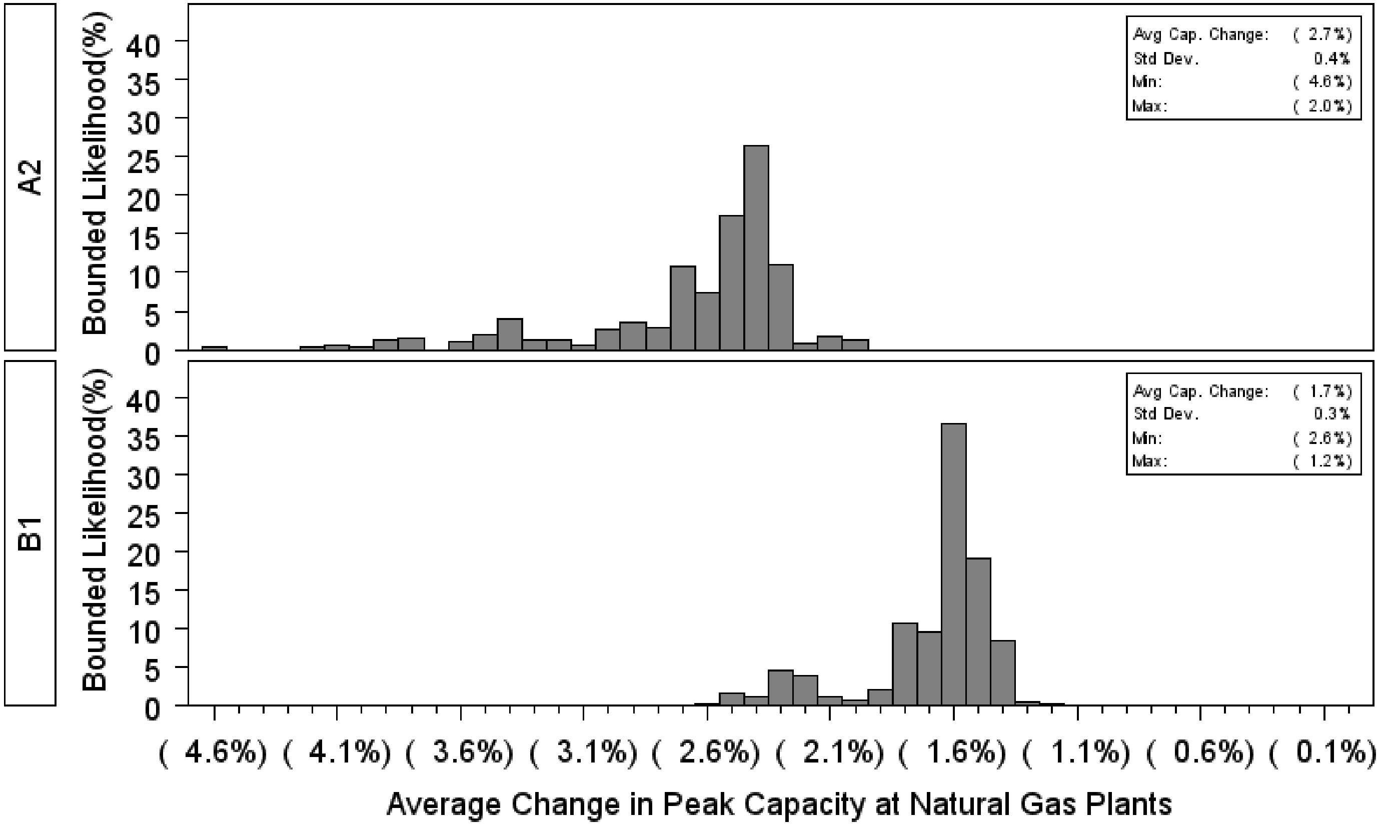
Temperature (Degrees Celsius)

- Estimated potential physical impacts without adaptation/growth scenarios and reported results using mapping and numerical simulation software.

Without additional cooling equipment, CA <u>substations</u> typically lose ~1.0% of capacity for every degree of ambient temperature above 30C.

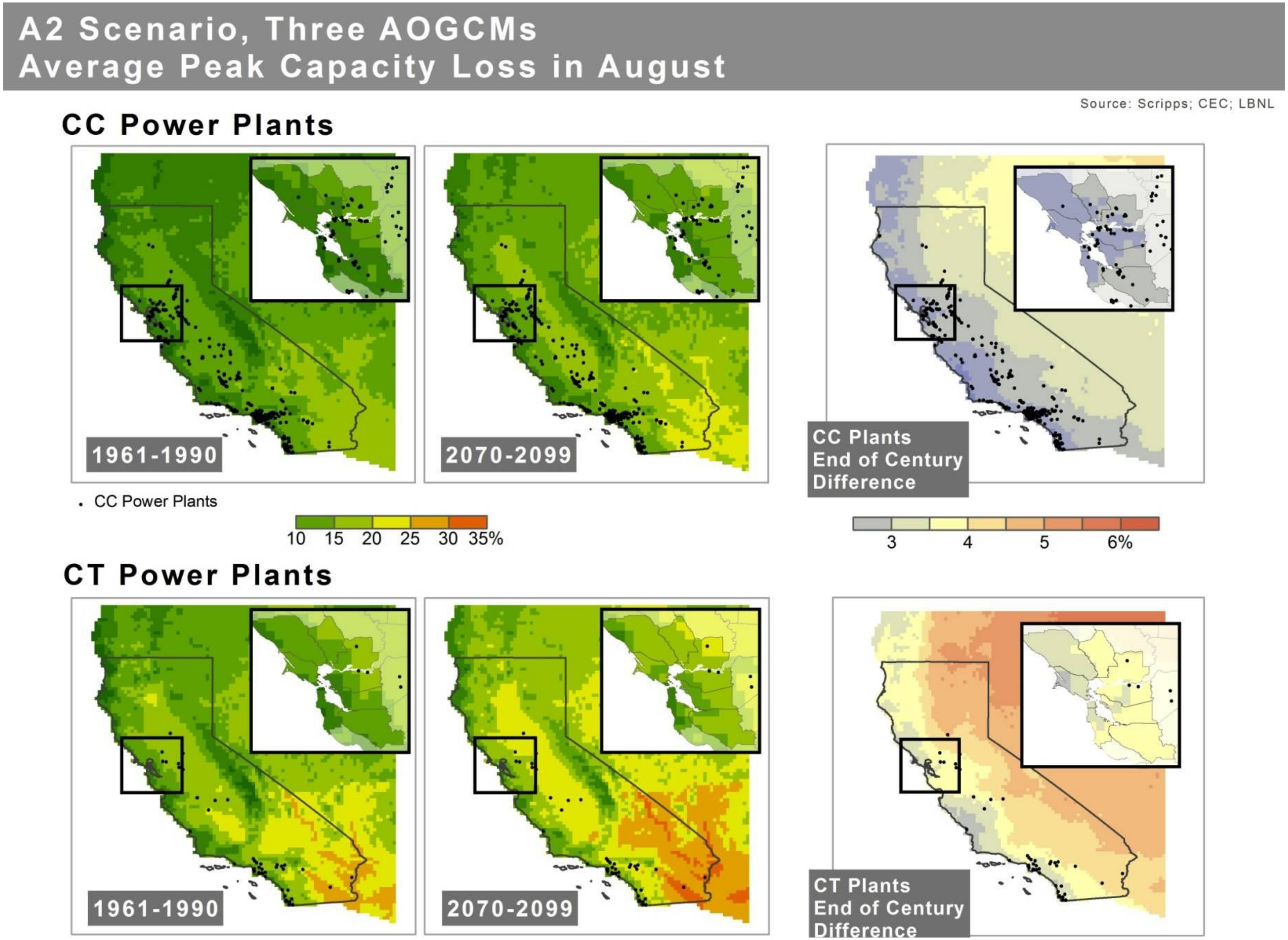
End-of-Century Incremental Impact Distributions

Natural gas-fired Power Plants



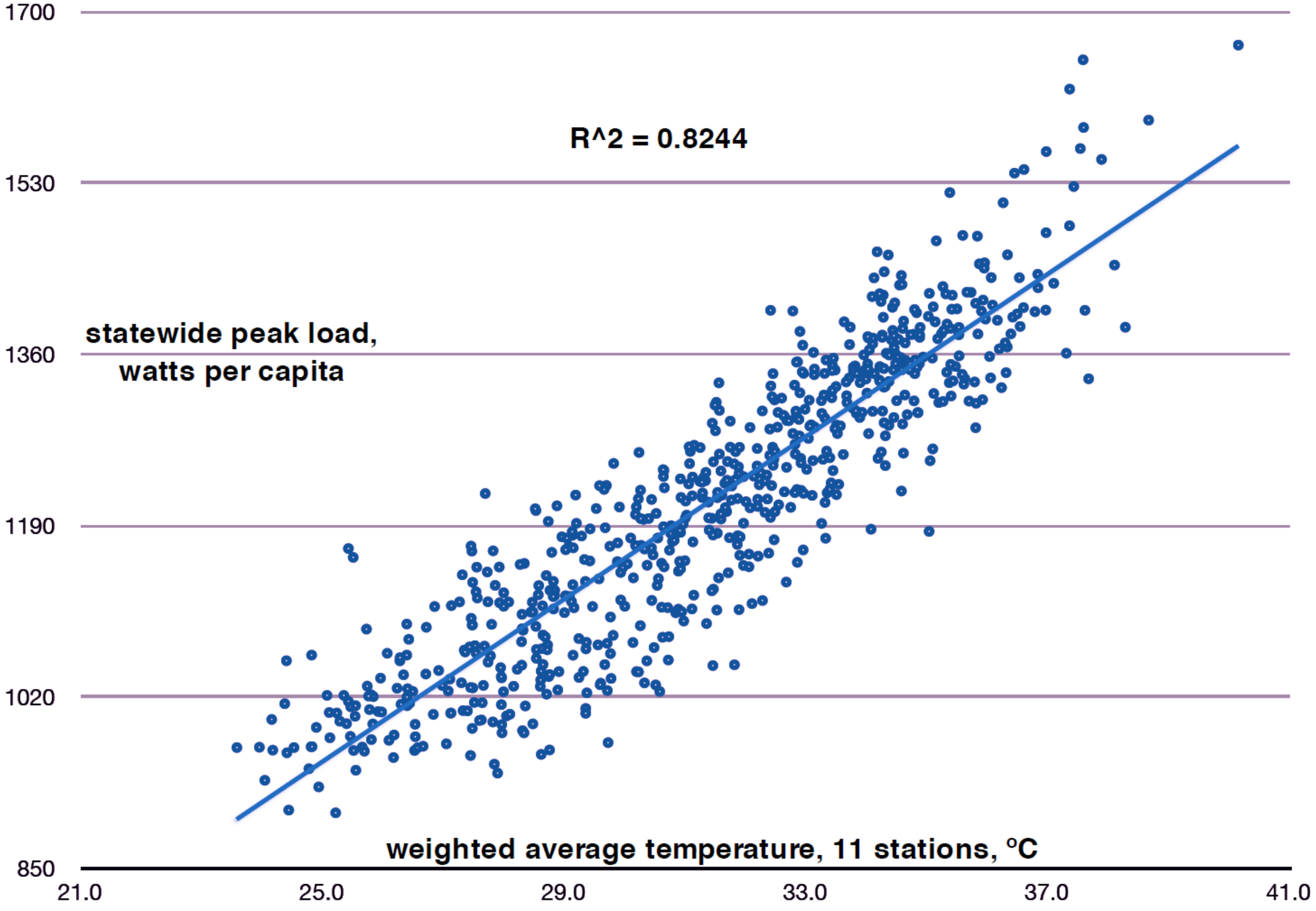
- *Warming temperatures may lead to* ***loss up to 4,000 megawatts (4%)*** *of available natural gas-fired power plant capacity.*
- *Incremental* losses are reported (i.e., losses above and beyond the losses estimated for the base period: 1961-1990).

End-of-Century Impact Mapping



Absolute Capacity Reductions — *Incremental Reduction*

Peak demand load vs. peak temperature



Electricity Demand and Supply: Results Summary

- **Peak Capacity Losses**

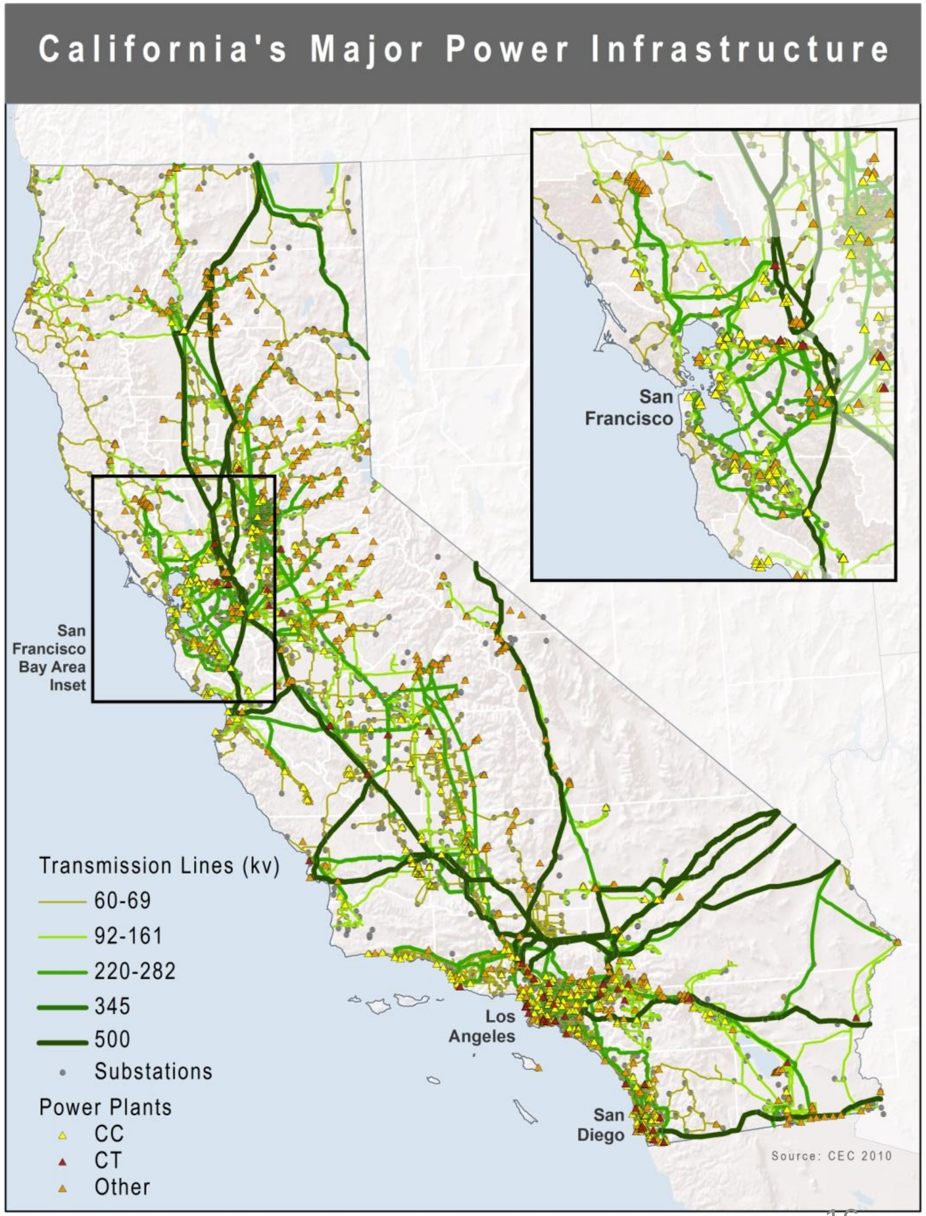
•Natural gas-fired power plants
  - up to 4000 MW (4%)

- Electricity supply sub-stations
  - 1.6% to 2.7%

- Transmission lines
  - Limited data on sizes, locations, and usage capacity
  - ~7%

- Cooling demand
  - 20% increase in peak load

- Demand and supply combined effect
  - 24%

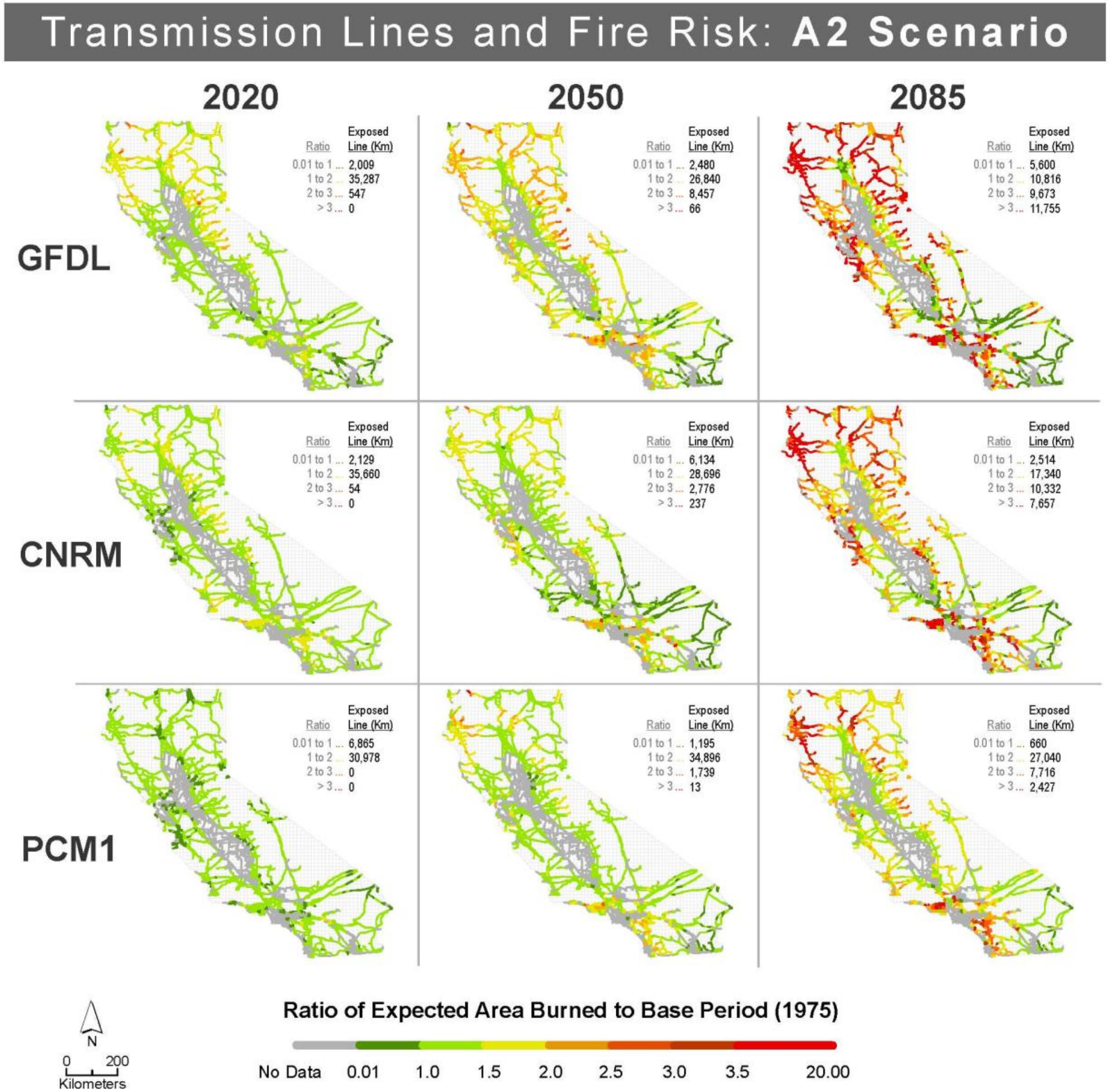


Overview of Research: Assessing vulnerability of….

2. Electricity infrastructure to **wildfires**.

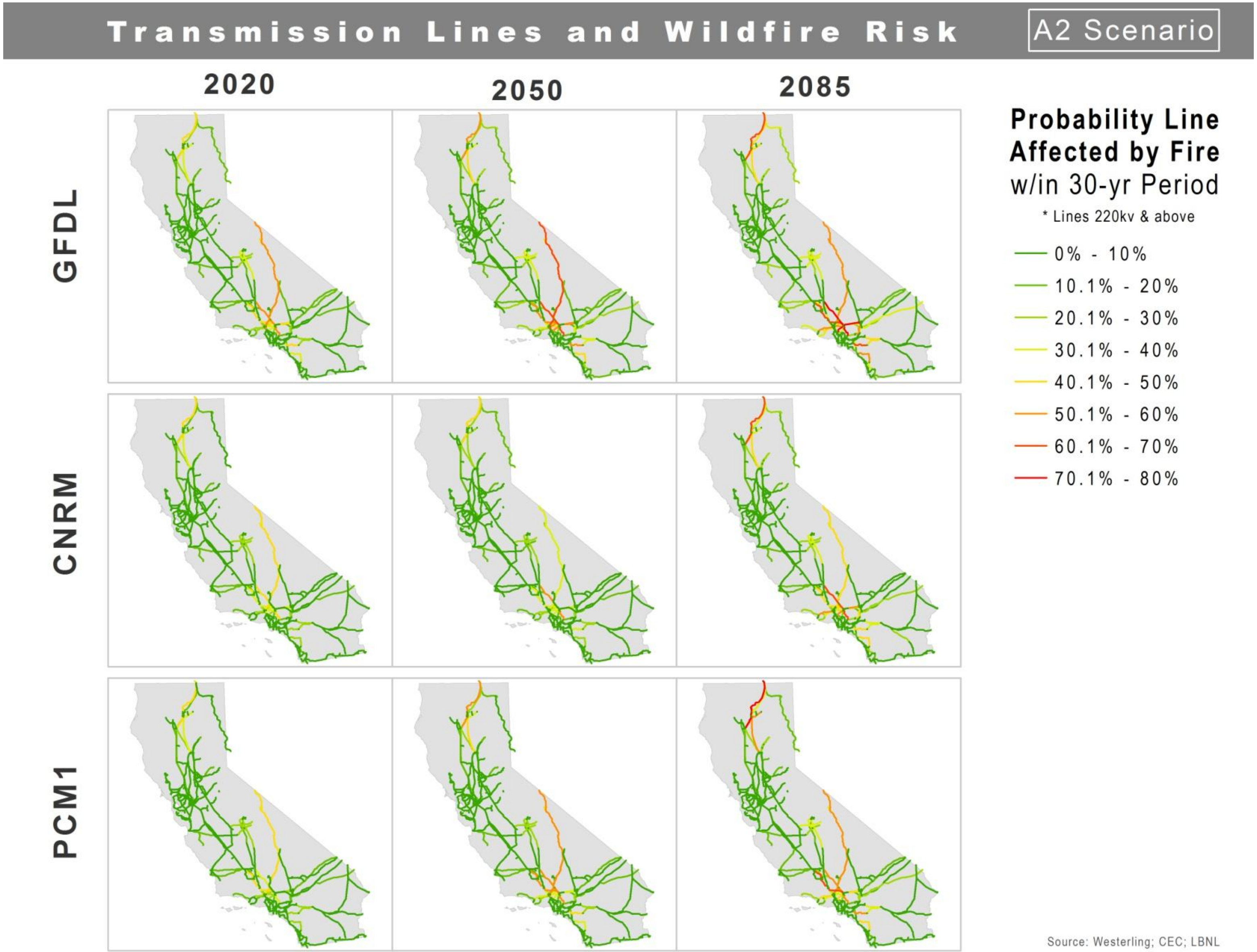
- *Discuss* **climate factors** affecting wildfires
- *Overlay* transmission lines on **near-term** spatial models of wildfire probability
- *Overlay* transmission lines on **long-term** spatial models of wildfire (as influenced by climate projections)
- *Quantify* transmission length of **lines exposed to wildfires** under modeled future climate scenarios

Length of Transmission Lines Potentially Impacted: Increase in burned area within cells ($1/8^0$)



- Coarse spatial resolution of fire projection data limited our impact analysis to the length of line in a fire-prone area.

Projected fire risk to transmission lines for the A2 scenario



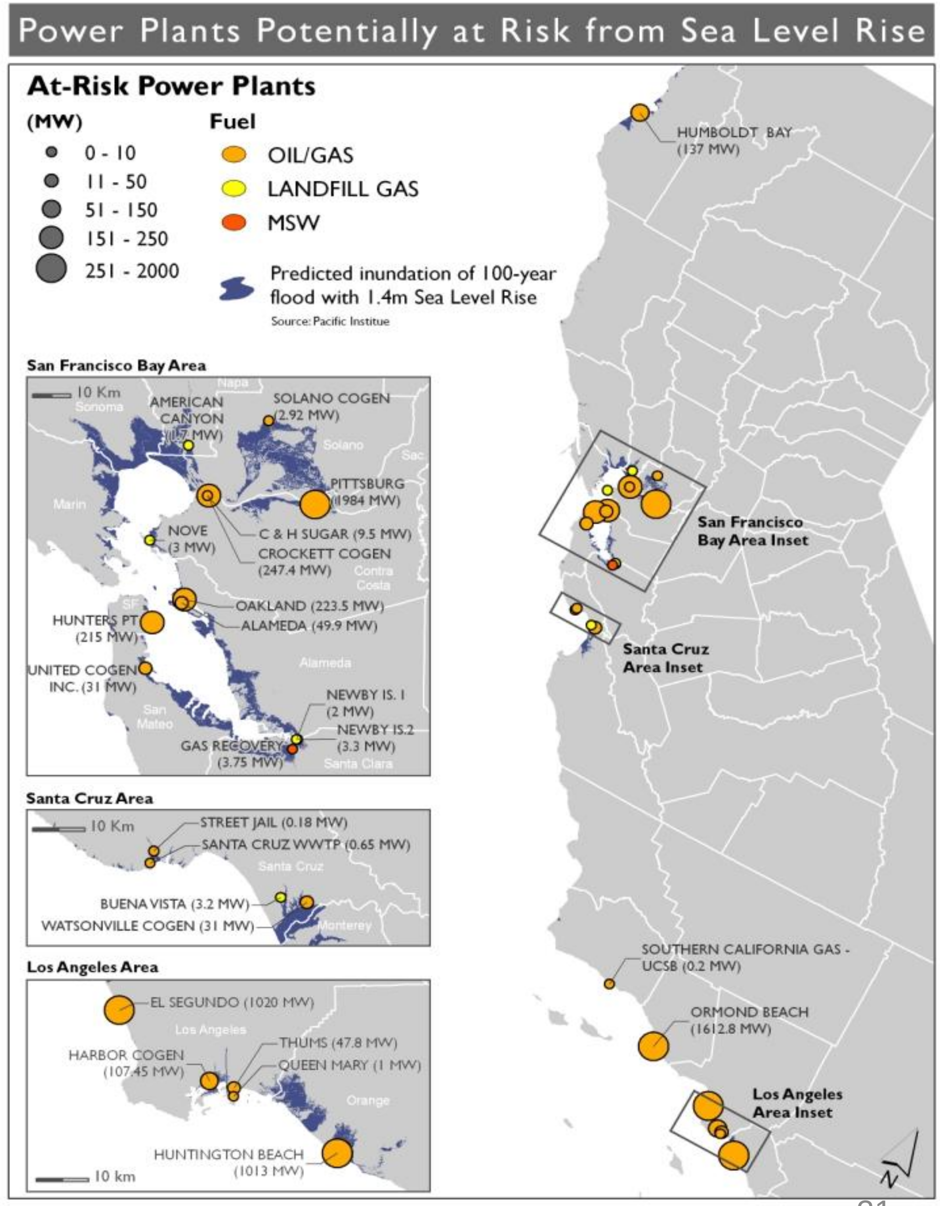
Overview of Research: Assessing vulnerability of….

3. *Electricity, natural gas, and other energy infrastructure* to **sea level rise**

- *Review* current sea level trends
- *Incorporate* data:
  - Land area affected by sea level rise (Pacific Institute, Knowles)
  - Power plant, substation, natural gas locations (CEC)
- *Mapping* analysis:
  - *Overlay* infrastructure locations over sea level areas
  - *Compare* LBNL and Pacific Institute study results

Sea Level Rise Impact Mapping & Comparisons

- Projected sea level rise – 1.4 meters
- 25 power plants and about 90 substations are vulnerable to sea level rise
- Humboldt Bay and Antioch Site visits indicated that coarse vertical resolution of CA topography may have over- or under-stated impacts in power plant locations.



Lessons Learned

- General lack of quantitatively-based impacts information for energy sector, but base of international literature is growing.
- Projected global heating demand reduction due to higher temperatures is larger than the increase in cooling demand
- Temperature impact on demand is much higher than on supply infrastructure
  - Impact on hydropower supply may increase or decrease generation depending on water supply conditions
- Impact of wildfires could potentially be significantly high
- More data and research are needed to evaluate wildfire and sea level rise impacts on the power sector infrastructure and temperature impacts on electricity transmission and distribution

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